Hazard Assessment of Thruster Plume Induced Surface Alteration for the InSight Mission

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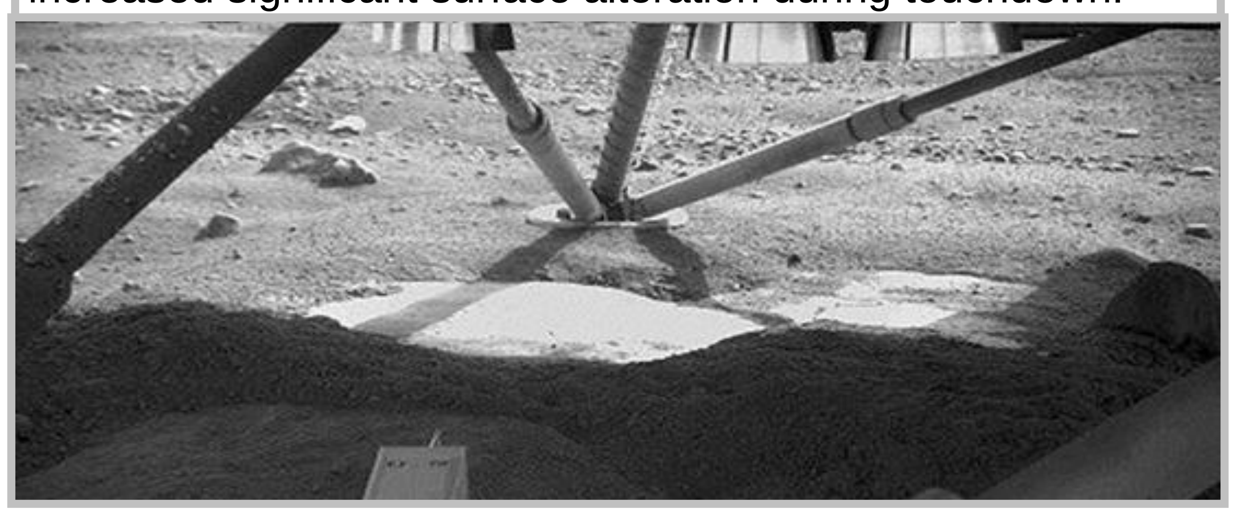
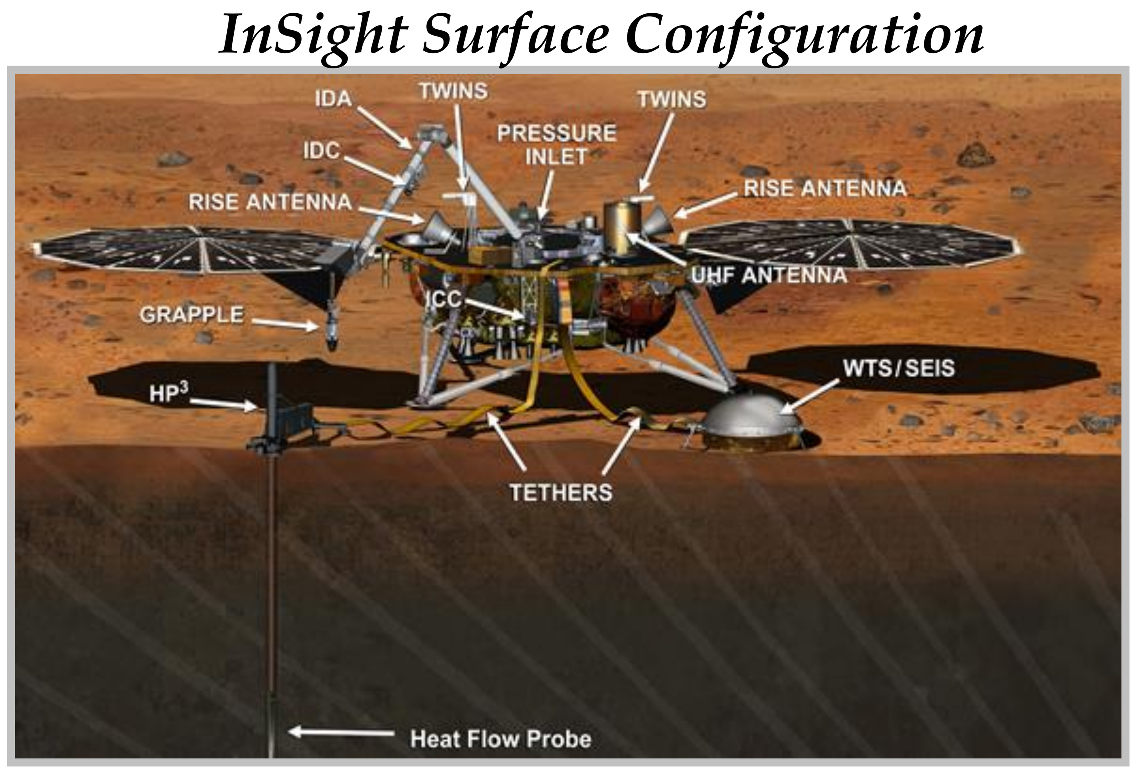
Mars Phoenix Experience

The InSight lander is nearly identical to the Phoenix lander which landed successfully in 2008. Soil beneath Phoenix' thrusters eroded down to shallow layer of competent subsurface ice. Such an ice layer is not present within InSight landing region, leading to concern over the potential of increased significant surface alteration during touchdown.



InSight Surface Configuration

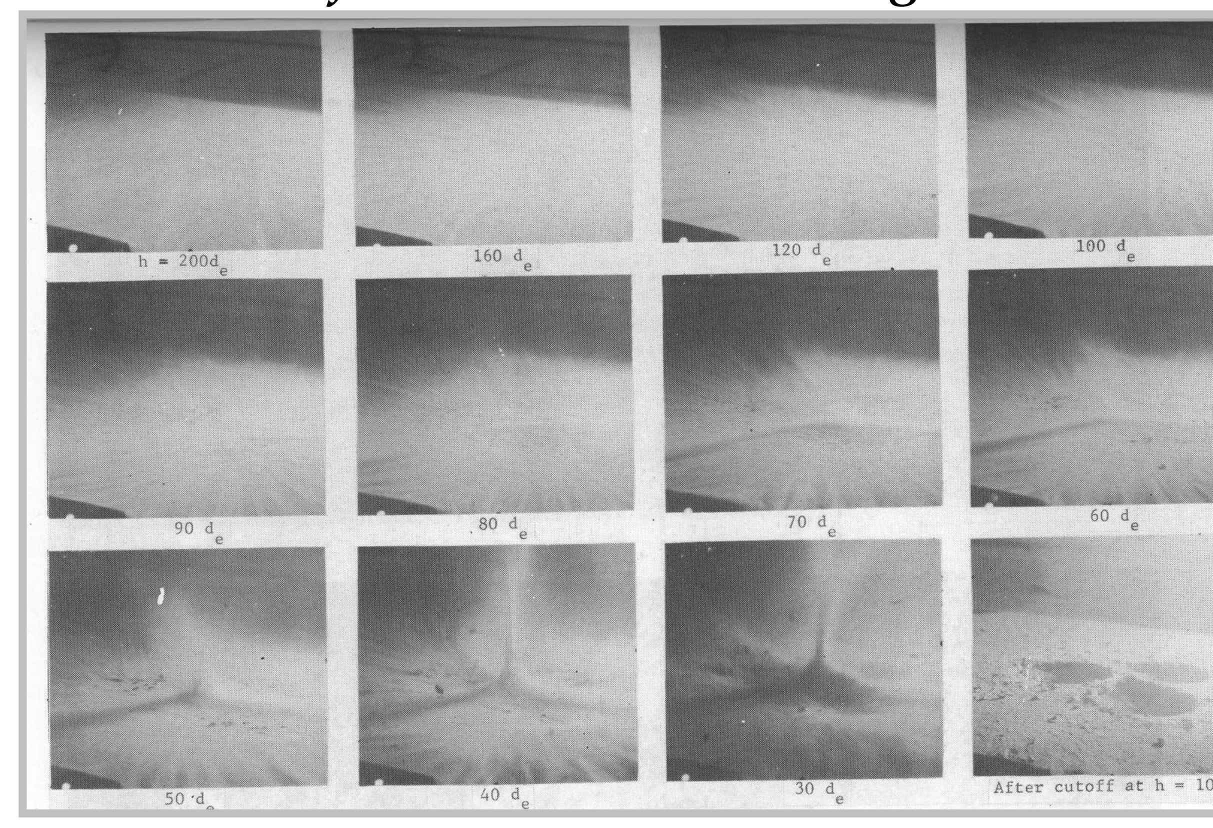


Background

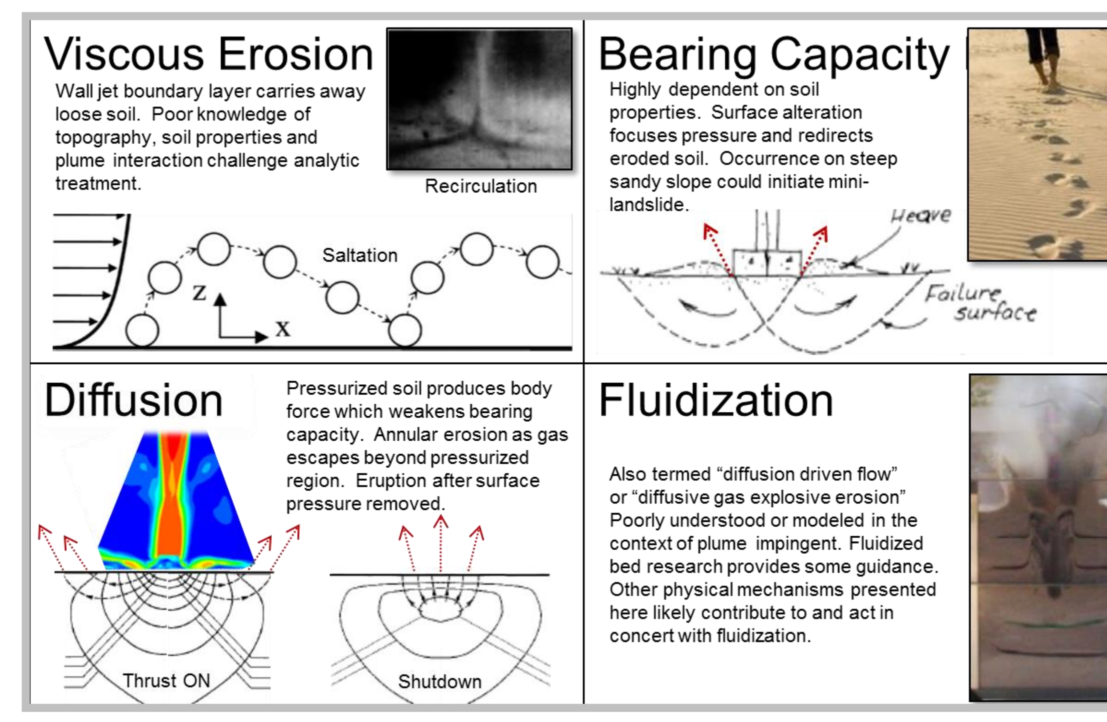
Abstract

Near-surface use of retrograde thrusters when landing on an unprepared surface will necessarily result in modification of local topography near the landing site. While the physical mechanisms governing erosion are generally understood for jet impingement on soil, the use of pulse-modulated thrusters introduces complex erosional mechanisms that are poorly understood. Under the constraints of the InSight mission it was not practical to develop and validate a rigorous method to accurately model pulse-modulated thruster interactions with the surface. Instead, focus was placed on pursuit of an approximate method to enable bounding risk assessment. An approach based on conservation principles, as described in this poster, was used to characterize the potential for site alteration during InSight landing. Associated mission risks were deemed to be acceptably low.

Surface Alteration Testing (1973)



Erosional Mechanisms

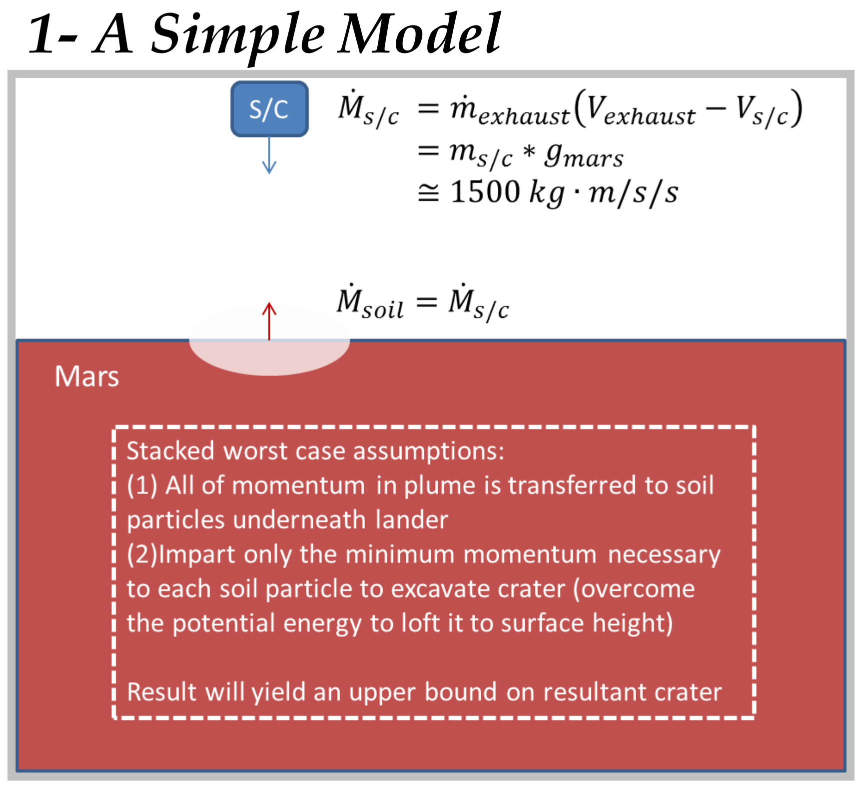


Method

A simplistic approach was leveraged to approximate and bound the potential for site alteration during InSight landing and the associated mission risks:

- 1-Formulate a simple model based on momentum conservation
- 2-Develop equations to calculate total momentum transfer necessary to excavate a given crater
- 3- Apply the method to heritage data for point validation
- 4- Generate bounding input parameters to assess InSight site alteration

1- A Simple Model



$$\dot{M}_{s/c} = \dot{m}_{exhaust}(V_{exhaust} - V_{s/c}) = m_{s/c} * g_{mars} \cong 1500\ kg \cdot m/s/s$$

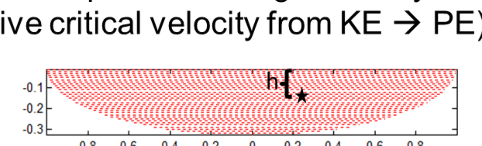
$$\dot{M}_{soil} = \dot{M}_{s/c}$$

Stacked worst case assumptions:
(1) All of momentum in plume is transferred to soil particles underneath lander
(2)Impart only the minimum momentum necessary to each soil particle to excavate crater (overcome the potential energy to loft it to surface height)

Result will yield an upper bound on resultant crater

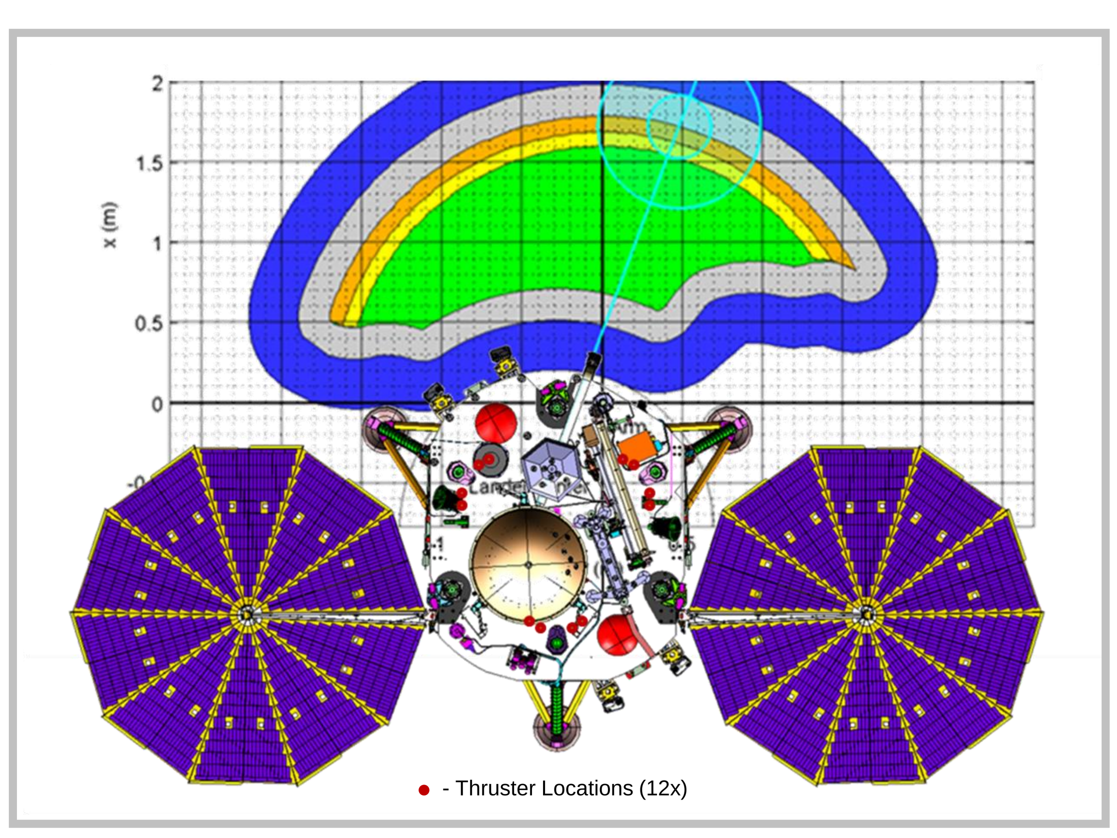
2- Momentum Transfer to Excavate Craters

- Momentum transfer to a given particle must provide enough velocity to reach the height of the crater rim, (derive critical velocity from KE → PE):
  - $M_{critical}$ = {$V_{critical}$} * {mass of particle}
  - $M_{critical}$ = {sqrt(2gh)} * {m}



- Assume any particles lofted to this height magically disappear…
- Assuming an axisymmetric crater with a defined depth-vs-diameter profile:

$$M_{required} = \int_{h_{min}}^{0} \{V_{critical}(h)\} * \{mass\ of\ particles\ at\ depth = h\}$$
$$= \int_{h_{min}}^{0} \{\sqrt{2g_m h}\} * \{\rho A(h) dh\}$$
$$= \{\sqrt{2g_m}\} * \{\rho(\pi r^2)\} \int_{h_{min}}^{0} \{r(h)^2 \sqrt{h}\, dh\}$$



Landed Configuration and Deployment Zone

3- Point Validation

Method was applied to compare momentum available in thruster plumes against the momentum transfer required to excavate an observed crater. All case studies yielded momentum transfer efficiencies of <50%.

	Momentum Transfer Efficiency	Comments
PHX Flight	28% / 1s	Likely mitigated by subsurface ice
Viking Flight	<1% / 1s	Mitigated by design (showerhead nozzle)
MSL Flight	<1% / 1s	Mitigated by design (nozzle height), bedrock
PHX Test	10%-30%	Subscale pulsed testing by Mehta, et al across range of particle sizes
Viking Analysis	< 42% / 1s	Based on max erosion estimate for original baseline bell nozzles
Morpheus Test	unknown	Method predicts entire simulant bed (1750kg) eroded within 0.12 seconds

4 -Bounding Risk Assessment

A small set of assumptions are necessary to enable bounding assessment:

- Soil Bulk Density
- Crater depth-vs-diameter profile
- Momentum Transfer Efficiency (Erosion Efficiency)
- Erosion Onset Altitude (Erosion Duration)
- Lander Tolerance (~40cm depth at footpad)

With conservative assumptions for the above, this analysis predicts InSight has robust margins of 200% - 500% against defined failure thresholds.

Conclusions

- Analysis technique developed based on conservation principles with the aim of bounding the level of flight risk posed by plume-induced site alteration.
  - Not a rigorous solution nor an accurate model of the interaction physics
  - Technique shown to successfully bound prior flight and test experience
  - Technique predicts InSight has healthy margins against failure scenarios
- Simplicity of the approach lends itself to application for bounding a wide range of thrust impingement problems regardless of planetary body of lander architecture

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